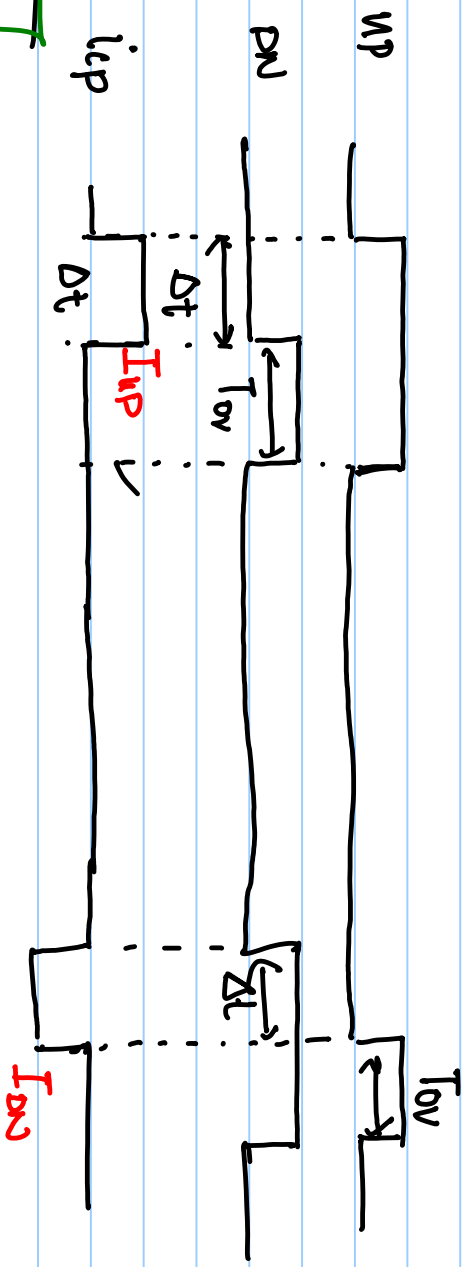
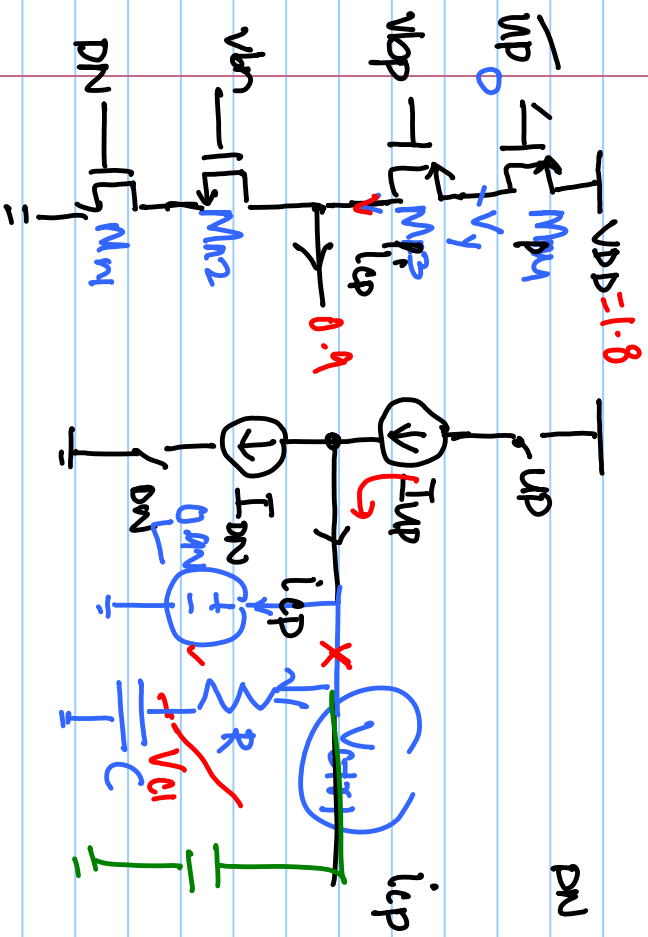


# Lecture # 36

## Charge pump



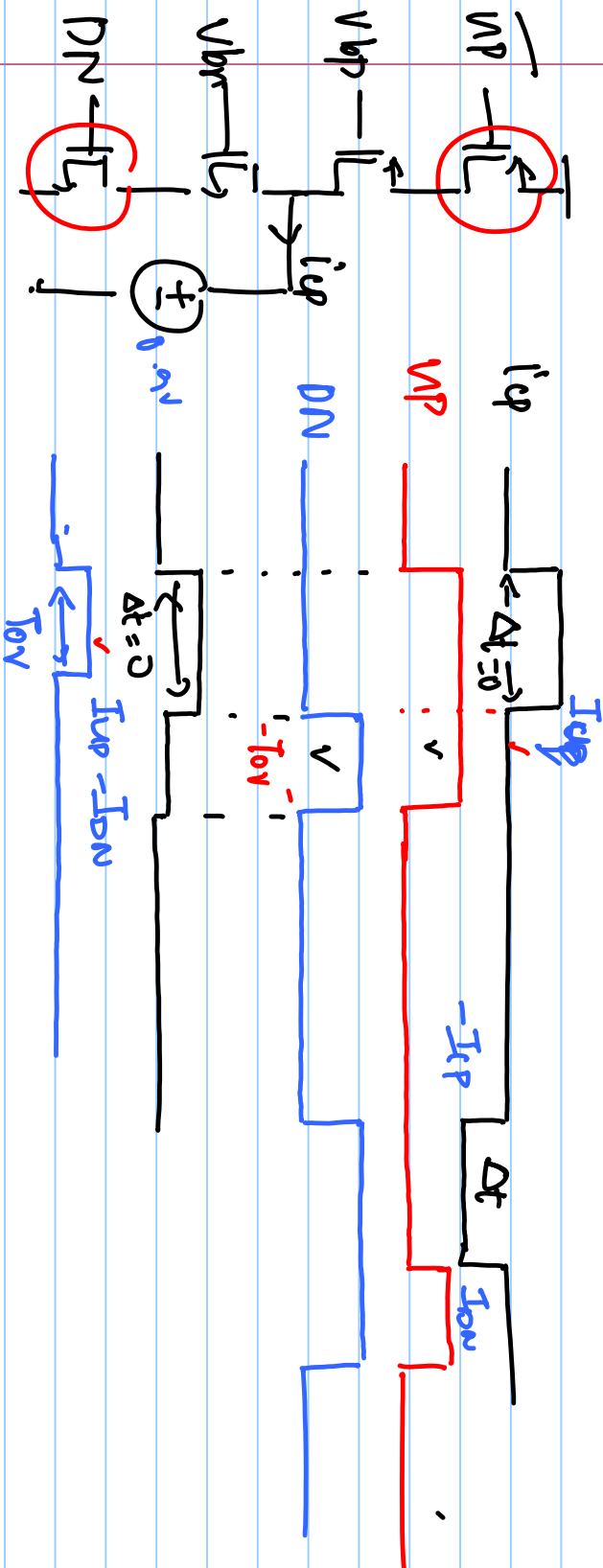
$$\begin{aligned}
 + \Delta t &\longrightarrow i_{CP} = I_{UP} \\
 - \Delta t &\longrightarrow i_{CP} = I_{DN} = I_{UP} = I_{CP} = 50 \mu A
 \end{aligned}$$

$M_{N1}, M_{P1}$  as switches

$M_{N2}, M_{P3}$  as current sources in saturation.

$$\begin{aligned}
 & \text{Circuit 1: } V_{GS} = 1.8V, V_{DS} = 0.85V, V_{GS} < V_{DS} \\
 & \text{Circuit 2: } V_{GS} = 1.75V, V_{DS} = 0.8V, V_{GS} < V_{DS} \\
 & \text{Circuit 3: } V_{GS} = 1.8V, V_{DS} = 0.9V, V_{GS} < V_{DS} \\
 & \text{Circuit 4: } V_{GS} = 1.75V, V_{DS} = 0.85V, V_{GS} < V_{DS}
 \end{aligned}$$

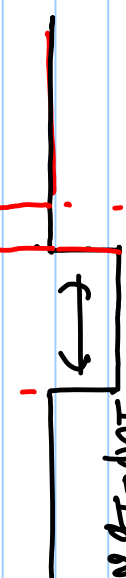
$$\begin{aligned}
 & 1.8V \text{ --- } 1.75V \\
 & 50\mu A \text{ --- } 50\mu A \\
 & 0.18\mu m \text{ --- } 0.18\mu m \\
 & 0.05V \text{ --- } 0.05V
 \end{aligned}$$



MP 

$$I_{DN} \times T_{OS} = (I_{UP} - I_{DN}) T_{OV}$$

PN 

$i_{CP}$  

$$\left. \begin{aligned} I_{UP} &= I_{CP} + \frac{\Delta I}{2} \\ I_{DN} &= I_{CP} - \frac{\Delta I}{2} \\ I_{UP} - I_{DN} &= \Delta I \end{aligned} \right\} \begin{aligned} T_{OS} &= \frac{(I_{CP} - \frac{\Delta I}{2}) T_{OS}}{\Delta I} = \Delta I \cdot T_{OV} \\ T_{OS} &= \frac{\Delta I}{(I_{CP} - \frac{\Delta I}{2})} \cdot T_{OV} \end{aligned}$$

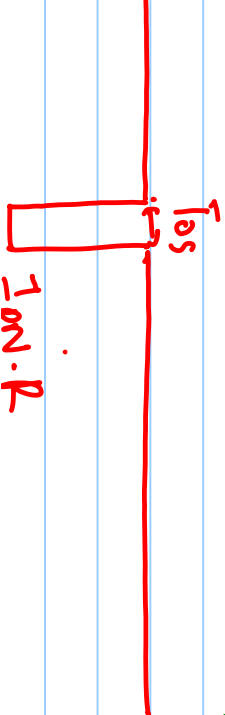
$V_{C1}$  

$$V_C = \frac{1}{C} \int i_{CP} dt$$

$$V_R = i_{CP} \cdot R$$

$V_R$  

$$V_{CH1} \rightarrow \text{Fwd} = \int f_{res} + k_{VCO} \cdot \underline{V_{CH1}}$$

$V_t$  

$$I_{ON} \cdot R$$

$$f_{out} = f_{free} + K_{vco} \cdot V_{ctrl}$$

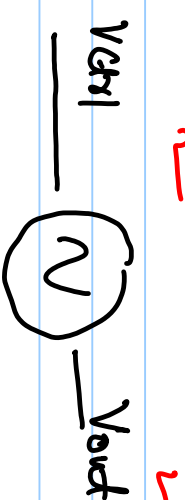
$\omega_k$ : Reference freq. in rad.

Fourier Series

$$V_{ctrl} = a_0 + \sum a_n \cos(n\omega_k t) + b_n \sin(n\omega_k t)$$

$$= f_{free} + K_{vco} [a_0 + a_1 \cos(\omega_k t)]$$

$$= (f_{free} + K_{vco} \cdot a_0) + K_{vco} \cdot a_1 \cos(\omega_k t)$$



$$V_{out} = \sin(2\pi \int f \cdot dt)$$

$$= \sin \left( 2\pi \left( f_{free} + K_{vco} \cdot a_0 \right) t + 2\pi K_{vco} \cdot a_1 \int \cos(\omega_k t) \cdot dt \right)$$

$$= \sin \left( \omega_0 t + \underbrace{2\pi K_{vco} \cdot a_1}_{\omega_R} \sin(\omega_k t) \right)$$

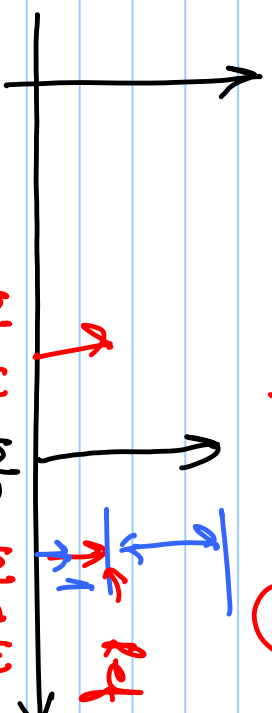
$\omega_R$   
B

$$V_{out} = \sin(\omega_0 t + \beta \sin(\omega_k t)) \rightarrow \text{Bessel functions.}$$

$$= \sin(\omega_0 t) \cdot \underbrace{\cos(\beta \sin(\omega_k t))}_{\theta \approx 0} + \sin(\beta \sin(\omega_k t)) \cdot \cos(\omega_0 t)$$

$$\approx \sin(\omega_0 t) + \beta \cdot \sin(\omega_R t) \cdot \cos(\omega_0 t)$$

$$= \sin(\omega_0 t) + \underbrace{\frac{\beta}{2}}_{\text{red}} \left[ \sin(\omega_0 + \omega_R t) + \sin(\omega_0 - \omega_R t) \right]$$



Ref. Spur. -x dBc Rel. Spur.

Rel. Spur. =  $20 \log_{10} \left( \frac{1}{\beta/2} \right)$  dBc

$$\beta = \frac{2\pi k_{v10} \cdot x}{\omega_R} \cdot a_1$$